MIDDLE FORK EEL SEDIMENT TMDL
LANDSLIDE ASSESSMENT
DRAFT

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PURPOSE-

The purpose of this investigation was to determine the amount of sediment delivered to the Middle Fork of the Eel River by landslides since 1940. Additionally, it was to assess the influence of land management activities on landslide rates. The work is part of the Total Maximum Daily Load (TMDL) program, for compliance with section (d), part 303 of the Clean Water Act. Other sediment sources are addressed in a companion document, Middle Fork Eel River Sediment TMDL Small Source Sediment Source Survey, Mendocino National Forest, 2003.

BACKGROUND

The framework for the Middle Fork Eel sediment analysis was developed at a meeting in the Forest Service Regional Office in Vallejo, California in February 2002, attended by personnel from the Forest Service, North Coast Water Quality Control Board, and U.S. EPA Region 9. At this meeting and in subsequent meetings, it was agreed that the Forest Service would produce tables showing sediment production by various time periods and management associations (roads or harvest), and two brief summary reports, the **landslide** assessment, and the **small source** assessment. A lengthy report was specifically discouraged by the EPA.

Landslide Sediment Assessment- The landslide component was coordinated by Juan de la Fuente, and focused on mass wasting processes. It utilized a basin-wide air photo inventory which: a) Mapped all visible landslides; b) Estimated sediment volume delivered to the stream system from those landslides; c) Assigned a management association (natural, road related, harvest related) to each landslide. Sequential air photos from 1952-2000 were used, and a small proportion of the inventoried landslides were visited in the field in 2002.
Small Source Sediment Assessment- The small source component was coordinated by Bob Faust, and addressed small sediment sources which in most cases would not be visible on air photos. This included roads, timber harvest units, gullies related to human activity, and stream bank erosion. It utilized a sampling technique, whereby field data were collected along the road and stream system, and findings then extrapolated to the remainder of the watershed (US Forest Service, 2003). Additionally, information on sediment production associated with storm damage to roads which was repaired under the Emergency Relief Federally Owned (ERFO) program was collected and summarized.

Landslide episodes are known to have occurred in the Middle Fork Eel River in 1955, 1964, in the middle 1970's, 1986, and 1997 (Bob Faust, personal communication, 2002). Flow records (Table 1) from the Middle Fork Eel, above its confluence with the main Eel River from 1966-2002 reveal that landslide episodes coincide with peak discharges in excess of 70,000 cubic feet per second (cfs). Such flows occurred in 1974, 1986, and 1997. Peak flows in 1955 and 1964 below Black Butte River were 89,100 cfs and 132,000 cfs respectively (Brown, 1971, page 40).

Structure and Future Revisions to this Report

Data tables (with the exception of Table 1) are grouped together, and located in Appendix 1. This is a draft report, and there will be some revisions to data summaries which will be completed in November 2003. These revisions are not expected to significantly change results (see Table 4).

TABLE 1

HYDROLOGIC DATA: STATION 114739

Middle Fork Eel River Above Dos Rios

(0.6 miles upstream of Eastman Creek)

Water Year	Discharge	Water Year	Discharge
1966	4500	1984	15600
1967	31400	1985	12300
1968	25400	1986	**74000**
1969	46200	1987	14400
1970	52700	1988	19000
1971	43300	1989	17400
1972	18700	1990	11700
1973	34300	1991	13800
1974	**72100**	1992	7500
1975	26700	1993	24200
1976	15600	1994	5670
1977	858	1995	56000
1978	22300	1996	17300
1979	14300	1997	**81200**
1980	46000	1998	28400
1981	14300	1999	18700
1982	35300	2000	25100
1983	38700	2001	6150

Management History- Much of the road system was in place prior to the 1964 flood, and regeneration harvesting on National Forest lands was very limited until the 1980's. However, some of the lands under other ownerships were logged by regeneration prescriptions prior to the 1970's.

METHODS

A basin-wide air photo inventory was conducted to determine landslide associated sediment delivery to the Middle Fork Eel River. Photo interpretive methods were similar to those used on the North Fork Eel TMDL (U.S. EPA, 2002), and on the Salmon River (US Forest Service, 1994). Photo years included 1952 through 2000. All landslides visible on the photos were mapped, down to a minimum dimension of 50 feet. Data recorded for each landslide included: slide type, photo year and number, length, width, depth, delivery percent, management association, certainty, channel association, and comments. Approximately 5% of the inventoried landslides were examined in the field to calibrate depth and percent delivery estimates made from air photos.

Selection of Air Photos and Determination of Photo Intervals

Due to differences in the availability of air photos in different parts of the watershed, the Middle Eel was subdivided into three separate areas, with different sequences of air photos used in each.

Upper Middle Eel & Elk Creek- Photo years 1952, 1969, 1981, 1998. Air photo mapping and field work done in 2002 primarily by William Snavely, with some field work by Juan de la Fuente.

Black Butte River- Photo years 1952, 1969, 1979, 1993, 1998. Work done by Juan de la Fuente, Alisha Miller, and Fred Levitan of North State Resources, and field work in 2002 by William Snavely and Juan de la Fuente.

Western Portion (Round Valley & Williams Cr.)- Photo years 1965, 1984, 2000. Work done primarily by Juan de la Fuente, with no field sampling.

Selection of Air Photo Intervals- Three air photo intervals were established for tracking sediment production since 1940. They were as follows:

Photo Interval	Beginning and End	Number of Years
1940-1969	summer 1940 through summer 1969	29

1970-1984	summer 1969 through summer 1984	15
1985-2002	summer 1984 through summer 2002	18
Total: 1940-2002	summer 1940 through summer 2002	62

Rationale for selecting 1940 as the starting date was that many of the landslides mapped on 1952 air photos were partially revegetated, revealing that they occurred prior to 1952, but probably not before 1940. The air photo intervals bracket the landslide producing storms in the watershed (1955, 1964, 1974, 1986, and 1997). Further, this selection allows separation of the most recent period (1985-2002) during which modern logging practices, Forest Service Best Management Practices, and standards of the Northwest Forest Plan were applied. The most recent air photos were 1998 for the upper Middle Eel and Black Butte River, and 2000 for the Round Valley and Williams Creek. However, 2002 was considered the end date for the landslide inventory because field inventories were conducted that year. It was recognized that the field inventories did not provide coverage of active landslides comparable to that of air photos, since most of this work was along roads. Uncertainties introduced by this approach are discussed in the Limitations/Uncertainties section.

Determining Management Association

Active landslides located within recently burned or logged areas were classified as fire or harvest-related, respectively. Similarly, landslides which are in the immediate proximity of roads, or below roads and connected with a visible gully, were classified as road related. A few landslides were identified along trails and transmission corridors, and these were lumped with roads in the data analysis (Table 5A, T and TC). Classifying landslides as management-related does not imply that the activity caused the landslide. Rather, it indicates that the management activity likely played some role in the activation of the landslide, but the magnitude of this effect is unknown. Landslides in burned areas were classified as natural.

Field Sampling Strategy

Criteria used for selecting landslides to be sampled in the field consisted of selecting sites with the following attributes:

1. Large sediment volume contributed to streams
2. Access (close proximity to roads)
3. Situated on Different Geologic types
4. Located on the Mendocino National Forest lands (landslides were not field sampled outside the National Forest boundary).
5. Located in areas distant from any other field observations.

Information obtained by field sampling was used to adjust air photo interpretations of delivered landslide volume.

Determining Landslide Volume Mobilized and Delivered to Streams

Landslide volumes were determined through aerial photography interpretation and field measurement and verification of about 100 landslides. The mobilized volume is the volume mobilized on the hillslope, and the delivered volume is the amount actually delivered to a stream course. It is important to note that sediment was classified as "delivered" when it was seen to enter any channel visible on air photos which appeared capable of carrying it on to larger streams, not just those identified as perennial or intermittent on the USGS topographic maps. Exceptions to this approach were made where the receiving stream entered a closed basin and did not connect to the remainder of the stream system. An example of this was the large rock slide/avalanche which occurred on Taliaferro Ridge, and delivered several million cubic yards of sediment to a pond at Bland's Cove in 2001. Since this pond is situated on a large landslide bench and drains only during winter high flows, the landslide debris was not classified as delivered to the stream system, since only a tiny fraction of fine sediment reached the Middle Fork Eel River.

Debris Slides- Simple debris slides (shallow, rapidly moving landslides) were mapped directly on air photos and transferred to topographic maps (with 5 meter resolution satellite imagery as a backdrop) through an ocular process. Length (distance up and down slope), and width (horizontal dimensions), and were then measured by a variety of methods, depending on the size of the feature, the estimated accuracy of the photo to map transfer, and steepness of slope. In some cases, the scale of the photo was determined for the elevation of the landslide, and width (along contour) was measured directly off the photo, and length measured from the map, after accounting for the effect of slope on map length versus slope length. On extremely steep slopes (100%), slope length is 1.4 times longer than map length, and on moderate slopes (50%), slope length is 1.2 times longer than map length. On slopes gentler than 50%, the difference is very small. Depth, and percent delivered to the stream system was estimated based on ocular evidence from the air photo (viewed stereoscopically) and professional judgment, tempered by information gained from the field sampling.

Slump-Earthflow Complexes- Although a geomorphic study of the Middle Fork of the Eel River was not performed as a part of this project, some of the larger slump/earthflow features were delineated as active when they exhibited extremely fresh landforms such as scarps, toes, and internal closed basins. These features were common on the Buck Rock and Leech Lake Mtn. 7 ½ minute quadrangles. Depths were estimated by drawing from previous experience and local field sampling, as well as taking into account published data on similar landslides (California Department of Water Resources 1970). The mobilized volume in these slump/earthflow complexes was much larger than volumes associated with most of the small debris slides. Volume "delivered" for these features was generally estimated at less than 1%. Depending on the size, debris slides on the toes of these complexes were either mapped as separate landslides, or lumped with the larger landslide, and the volume they delivered to the stream accounted for in the percent delivery factor for the larger feature.

Earthflows- Sediment delivery from earthflows was estimated the same as other deep landslides (by measuring debris slide scars) with the following exception. Shallow earthflows in prairies which exhibited rumpled textures on air photos, suggesting rapid creep, and were also traversed by abundant, fresh gullies (relative to gullies in nearby earthflows) were also mapped as "active". Volume delivered to the stream system by these features was estimated by measuring total gully length, and width and estimating depth within the feature, and assuming that most of this mobilized material entered the stream system. There is considerably more uncertainty in measuring this type of sediment delivery than in estimating volume from debris slide scars. However, since only about 40 of these features were mapped, the total contribution of sediment estimated for this process is small relative to that from the other landslide processes, and consequently, has little effect on basin totals. A few earthflows of this type, about 60 acres in size, were observed just west of the Middle Eel Watershed boundary, about 4 miles west of the town of Covelo, in the Covelo West 7 ½ minute quadrangle (near the center of the west margin). These features were unique, in that they had clearly mobilized throughout (the ground surface was fully disrupted) on the 1965 air photos, and gullies were very fresh.

Multiple Movement Episodes

Many landslides exhibited fresh movement on several air photo years. Each successive photo year was examined, and landslides which had been mapped on previous years were evaluated to see if they had moved again on the newer photos (based on presence or absence of vegetation). There is considerable uncertainty in making this call, since different sites revegetate at different rates, depending on soil depth, aspect, groundwater conditions, etc. If a previously active slide was barren of vegetation on a given air photo, it was assumed to have moved during that photo interval. In the case of debris slides, depths used to compute landslide volume were assumed to be considerably shallower in successive movements than in the initial movement.

Focus on Black Butte River for Air Photo Investigation

Black Butte River was selected for a more detailed look at timing of landslides (more photo years examined) than the remainder of the area, due to availability of photos, and the presence of a representative mix of rock types. Photos from 1952, 1969, 1979, 1993 (small area), and 1998 were examined.

Conversion of Landslide Volume (Cubic Yards) to Tons

A conversion factor of 1.5 tons per cubic yard was used to convert cubic yards to tons. This assumes a density of about 111 pounds per cubic foot, or 3000 pounds per cubic yard. It is important to note that landslide derived sediment typically consists of rock soil mixtures, and there is a broad range in the weight of such mixtures (Appendix 5), and this can have a significant effect on the conversion. For example, in-situ sand weighs about 1.4 tons per cubic yard, whereas in-situ sandstone rock weighs about 2.1 tons per cubic yard. On the other hand, fine reservoir sediment from Lake Pillsbury is estimated to weigh about 0.986 tons per cubic yard (Brown, 1971)

GIS and Data Base Methods

Landslides were digitized in ArcInfo, and a GIS coverage developed. Numbers were assigned to each landslide, beginning with the USGS quadrangle number, and the landslides then numbered sequentially. For example, the first landslide mapped on the Jamison Ridge 7 ½ minute quadrangle was numbered 5822-001. Each landslide was assigned a unique number, and if the same polygon moved in subsequent years, it was assigned a new number. Data for individual landslides were recorded in the Regions Table, and this was linked to GIS polygons via the Polygon Table. Thus, individual landslides were treated as regions, and each region may consist of several GIS polygons where movement occurs in multiple years at a site. In this way, overlapping landslides were accounted for. The Regions Table was then input to an Access Data base, and queries were made for combinations of factors such as landslide volume by photo year by ownership by watershed.

Combining Landslide and Small Source Sediment Analysis Data

Tables 4, 5A, 5B, 5C, 5D, 6, and 7 combine sediment volumes from the landslide assessment and the small source assessment. Table 7, “All Ownerships”, lists sediment production in cubic yards per year for roads (2889), gullies (171), timber harvest (36), and Streambanks (303,244). Values for roads, gullies, timber harvest were determined from field inventories, considering the time period 1996-2002. In comparing these numbers to other watersheds, it is important to take into account that they do not include the effects of the 1955 and 1964 flood, and that management practices have changed over the years. If the effects of the 1964 and 1955 floods were incorporated into the estimated erosion rates, they would increase substantially, possibly by an order of magnitude or more (Table 5A). Streambank erosion rates were taken from work by Mary Raines on Grouse Creek, and include the effects of large floods such as that in 1964. These numbers are large, and there is considerably more uncertainty than that associated with the landslide volume estimates.

FINDINGS

Summary

1. A total of 4,122 landslides were inventoried in the Middle Eel basin, delivering a total of 24,969,836 cubic yards of sediment to the stream system, and occupying 13,526 acres (Table 2).The preponderance of the landslides in the Middle Fork Eel (both number and sediment volume) occurred during the photo interval 1940-1969 (Table 2).
2. Management associated landslides account for about 3.8% of the total volume from 1940-2002, but due to some uncertainty of assigning management association to some landslides, the value ranges fro 3.8 to 8.2 for this time period (Table 4), and 1.7% (Table 7) for 1985-2002 (a range would apply here also).
3. A large proportion of the total delivered sediment originated from the toes of large deep seated landslides adjacent to streams. In some cases, the entire landslide appeared to have been mobilized (scarps visible in the upper parts), and in others, the only evidence of movement is the debris slides on the toes. A few of these large deep seated landslides account for a large proportion of the total delivered landslide sediment volume. Many deep seated landslides exhibited multiple years of activity, shedding debris slides of varying sizes at different times.
4. Some large earthflows contributed very large volumes to the stream system. One such example in Grist Creek (Covelo West 7 ½ minute quadrangle) appears to have experienced rapid failure. This landslide mobilized about 13 million cubic yards of debris, and delivered about ½

million cubic yards of sediment to the stream.

5. Debris flows associated with the flood of 1997 affecting long lengths of channel are uncommon relative to areas in the Klamath Mountains during that event (USFS 1998).
6. The mapped active landslides form a pattern paralleling some of the major streams, and did not display any obvious affinity with specific bedrock units (Map 1).
7. Intensive tractor logging of some of the gentle uplands in Black Butte River watershed appears to have generated a lot of sediment from surface erosion, but not much landsliding.
8. Effects of 1955 and 1964 Floods- Landslide frequency is extremely high during the 1940-1969 interval, accounting for 78% of the total landslide volume delivered to the stream system (Table 2). Numerous studies discuss the landsliding associated with these floods (Brown 1971 p. 48).

Landslide Volume by Subwatershed-

Table 3 displays landslide volume by subwatershed in cubic yards per year and cubic yards per acre per year and tons per square mile per year. Black Butte River (Map 1) delivered the largest landslide sediment volume during the interval 1940-2002 (9,928,532 cubic yards). Similarly, it produced landslide sediment at the highest rate in cubic yards per acre per year (1.55). This compares to 0.29 for the Upper Middle Eel, and 0.84 for the entire Middle Eel.

Landslide Volume by Subwatershed by Disturbance Class-

During the time period 1940-2002, landslides associated with human activity (roads and harvest) accounted for 3.8% to 8.2% (Table 4). This range will be refined in the final report.

Sediment production all Sources 1985-2002

From 1985-2002, human activity was associated with 56,535 cubic yards, or 1.7% of the total for that interval (Table 7). As with values for 1940-2002, this number may change slightly when data revisions are completed.

Comparison With Other Studies

Table 9 displays landslide sediment production figures for the North Fork Eel, the Middle Fork Eel (this study), and South Fork Eel. Values for landslide sediment reported for the Middle Eel in this study are about 5 times higher than those reported for the North Fork Eel (Forest Service lands only). Total sediment production reported by the USGS in Middle Fork Eel is 7 times the landslide volume estimated by this study, but are based on the time period 1957-1967.

The USFS estimates for landslide volume done in 2001 are slightly higher than those presented by this study (1.21 times higher).

LIMITATIONS/UNCERTAINTIES

Overlap Between Landslides and Stream Bank Erosion Values- All large stream bank slides which were visible on air photos were mapped as part of the landslide inventory for Middle Fork Eel TMDL, as were a small number of the largest gullies which appeared to be experiencing active debris sliding. The river basin study conducted by the Soil Conservation Service (1970) included streambank landslides up to 200 feet long in their streambank erosion calculations. As a result, adding their streambank erosion figures to the landslide volumes determined for the Middle Eel TMDL would double count this source.

Determination of Natural Versus Management Related Sedimentation- Landslides immediately adjacent to roads or skid trails were classified as road-related, though a direct cause-effect relationship is not implied, since this is difficult to establish from air photo evidence alone. Similarly, a landslide identified within a regeneration harvest unit was classified as logging related. The same approach is used for burned areas.

The Denominator of the Human/Natural Ratio- Determining the volume of landslide sediment delivered to the stream system from natural sources as well as natural stream bank erosion is difficult, yet critical to the TMDL process. The bank erosion figures are large, and considerably less reliable than the landslide volumes.

Uncertainties in Measuring Sediment From Large Deep Landslides- The method used on the Middle Fork Eel TMDL for determining landslide sediment delivery, from large deep-seated landslide consisted primarily of measuring debris slide scars on air photos, and estimating the % of material which entered the stream. This approach provides a minimum value of delivered landslide volume, and is relatively unambiguous and reproducible relative to other approaches.

Fire- Data on fire association with active landslides is limited by the difficulty in keeping track of burned areas in the watershed, and revegetation over time.

Harvest- Harvest effects may be underestimated for the earlier time periods (Pre-1980), since we only called a slide harvest-related if it was in a clearcut, and most of the logging prior to 1980 was partial cutting (many of the landslides were probably in areas which had been partially logged, but we couldn't be sure on the air photos.

Uncertainty Associated With Placing Landslides Within Photo Intervals- The fact that air photos of the same dates were not uniformly available across the Middle Fork of the Eel River introduced some uncertainty in the assignment of landslides to one of the three air photo intervals. This applies to landslides which occurred from 1965-1969, and 1980-1983. For example, a landslide occurring in 1968 in the Round Valley area would first appear on the 1984 photos, since 1965, 1984, and 2000 photos were available there, and it would be assigned to the 1970-1984 interval. In contrast, a slide occurring that same year (1968) in Black Butte River would first appear on the 1969 air photos, since photos from 1952, 1969, 1979, 1993, and 1998 were available there. As a result, this landslide would be assigned to the 1940-1969 interval, even though it occurred the same year (1968) as the previous example from the Round Valley area which would have been placed in the 1970-1984 interval. This uncertainty applies to landslides which occurred from 1965-1969, and 1980-1983. Examination of flow records (Table 1) suggests that these were probably not years with abundant landslides, since peak flows reached a maximum of 46,200 cubic feet per second (1969) during those years. However, anecdotal accounts suggest that there were landslides in 1982-1983. In summary, the uncertainty associated with this issue would have little effect on the finding that the 1940-1969 is the predominant landslide time period, but it could have a small effect on the relative importance of the 1970-1984 and 1985-2000 time periods.

Undetermined Age and Management Association for Some Landslides- Tables 2 and 4 list some landslides with unknown management and date. The effect of this uncertainty on the proportion of management related sediment is displayed on Table 4. These uncertainties will be addressed in the final report of November 2003.

Lack of Air Photo Coverage 1998-2002 and 2000-2002 in Parts of the Watershed- Since landslide inventories were limited to filed reconnainnance in the eastern part of the watershed and none in the Round Valley part, this leads to two uncertainties; a) Some landlsides may have been missed those years; b) Calculations of annual rates over the entire inventory period (1940-2002) would be affected by a factor of 60/62 (0.97) and 58/62 (0.94)respectively.

Limitations of Air Photo Inventory- Air photo inventory is effective at identifying debris slides which leave barren scars, down to a size of about 50 feet in maximum dimension. However, under a timber canopy, barren debris slides as large as 150 feet maximum dimension can be missed. Earthflow movement which does not destroy vegetation or create large scarps in open areas cannot be detected on air photos. For example, large active earthflows studied by the California Department of Water Resources as part of the proposed Dos Rios dam site (California Department of Water Resources 1970) were not identified by the photo inventory, but debris slides on the margins of these features were identified. Thus, smaller slides are identified in open areas and along roads than can be seen under a timber canopy, and earthflows contributing large volumes of sediment to streams may be missed if they do not have bare debris slide areas. Also, in tractor logged areas, a large proportion of the landscape is disturbed, and it is difficult to distinguish small debris slides from skid roads, and landings. Thus, such areas may have more small landslides than are identified on the air photos.

Landslide Disturbance Class and Photo Year- At the time of preparation of this report, a number of landslides were not characterized in terms of management association. Most of these are natural, but some are road or harvest related.   This classification will be completed in the near future and added to the landslide regions data base, but it is not expected to significantly affect proportions of management-related and natural landslides. Additionally, a small number of landslides did not have photo years associated with them at the time of preparation of this report, and these are being reviewed, and changes made to the landslide regions data base.

Discussion- Due to the large number of landslides inventoried (over 4,000), a large volume of data were collected, and the risk of human error in recording and manipulating the information is worthy of note.   Reasonable care was taken in the process, and several QC checks are underway to assure that no significant errors were made.

PROJECT PARTICIPANTS

Primary contributors to this study included, in alphabetical order:

Bonnie Allison- Scanned landslide data and plotted work maps.
Juan de la Fuente- Project coordination, Landslide mapping in Black Butte, Round Valley, Elk-Thatcher, field sampling of landslides, final report.
Don Elder- GIS and data base design and application, bedrock group stratification, Access data queries, GIS overlays and maps.
Bob Faust- Field reconnaissance assistance, logistics for field work.
Hal Fiore- Field review of inner gorge landslides in Cold Creek near Jenks Camp.
Bob Jester- Scanning and labeling polygons, plotting maps

Alisha Miller- Mapping landslides in Black Butte, comparison of landslide sediment studies in adjacent watersheds, digitizing Covelo 1:100,000 geologic map, spreadsheet design and date entry.
North State Resources- Fred Levitan, mapped active landslides on 1952, and 1969 air photos for Black Butte River, and recorded data on delivered sediment volume.
Mark Smith- Digitizing Covelo 1:100,000 geologic map, providing landslide sediment production for the North Fork Eel TMDL.
William Snavely- Air photo landslide mapping in Upper Middle Eel, Elk, Williams Thatcher, field sampling of landslides, data entry, summary report.
Richard Van de Water- Digitizing Active Landslides, plotting maps, GIS overlays and queries.

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Add Eel River Offshore Basin Report

APPENDIX 2: PREVIOUS STUDIES

Several studies of landslide sediment production have been conducted in the Eel River basin, and several specifically in the Middle Fork. These studies were reviewed, and provided valuable insights into the role of landsliding in the total sediment budget. Several are summarized in Appendix 1.

1970- Middle Fork Eel River Landslides Investigation: California Department of Water Resources-. This study was done as part of the investigation for the proposed Dos Rios Dam site, and is wholly within the Middle Ford Eel watershed. It involved detailed field mapping, drilling, installing inclinometers, and conducting seismic surveys on a number of landslides to determine depth of failure and movement rates. A primary focus of the study was to identify landslides which had the potential to fail catastrophically into the proposed reservoir, and generate a wave which could overtop the dam. The study found that landslide depths ranged from about 10 to 190 feet, and movement rates from less than an inch per year to 80 feet per year.

1970- Sediment Yield and Land Treatment Appendix No. 1 Eel and Mad River Basins: Soil Conservation Service. This study assessed sediment production in the major rivers of NW California. In the Middle Eel, it used air photo techniques and sampled about 25% of the watershed, identifying 738 landslides, visiting 10% of these in the field. It estimated landslide production for the period 1941-1965 to be 366 acre feet per year (page 69). Using their watershed area figure of 481,920 acres, this equates to 1.23 cubic yards per acre per year. This value would reflect the effects of the 1955 and 1964 floods.

1971- Sedimentation in the Middle Fork Eel River Basin: California. USGS Open File Report. This study estimated sediment production for the Middle Fork Eel at 4,245,000 tons per year (5.8 cubic yards per acre per year).
1971- Sediment Transport and Turbidity in the Eel River Basin: California: U.S. Geological Survey Water-Supply Paper 1986. This study analyzed discharge and suspended sediment data from recording stations on the Eel River before and after the 1964 flood. It found that the Middle Fork of the Eel below the confluence of Black Butte River had one of the highest suspended sediment discharges ever recorded in the United States (8,000 tons per square mile of watershed area per year over the period 1963-1967). It stated that peak flows during the 1964 flood reached the base of the highway bridge about a half mile upsteam of the mouth of the Middle Fork, 68 vertical feet above the steam bed. Also, the bed of Black Butte River at the gaging station aggraded 8 feet during the 1964 flood, and continued to aggrade slightly in subsequent years.

1973-Geology and Sediment Production for Ten Eel River Landslides: California Department of Water Resources. This study examined some of the largest landslides along the Eel River (outside the Middle Fork) from English Ridge to the confluence with the South Fork. It utilized observations made by railroad workers, and identified landslide depths of a few tens of feet to 150 feet, and movement rates of from less than one to 150 feet per year.

1982- Middle Fork Eel River Watershed Erosion Investigation: California Department of Water Resources. This study involved air photo analysis which included mapping landslide deposits and active landslides on color 1979 and black and white 1981 air photos. A landslide map was produced, which classified 13.7% of the Middle Fork Eel as landslide deposit, and 1.4% of the basin as active landslides, with a range of 3.6% in Salt creek, and 1.8% in the Middle Eel above the Ranger Station, and 0.4% in Mill Creek. It also classified 4.4% of the basin (21,120 acres) as “active mantle creep”, making the total active category 5.8% of the watershed.

1999- South Fork Eel TMDL: Study conducted by Tetra Tech For Stillwater Sciences. It examined landslide sediment production for several time periods, as follows.

Time Period	Cubic Yards per Acre Per Year
1981-1996:	0.54
1966-1981:	1.03
1942-1965:	2.26

2001- Watershed Condition Assessment: Northern Province. US Forest Service. This analysis used a bedrock compilation map for the Northern Province of the California Region of the Forest Service (Mendocino, Six Rivers, Shasta Trinity, and Klamath National Forests) to estimate landslide sediment production from 5th field watersheds. Landslide sediment production coefficients in cubic yards per acre per year, derived on the Salmon River (U.S. Forest Service, 1994), and Six Rivers National Forests were developed for the bedrock units within the basin, and landslide sediment production was estimated. Application of these coefficients to the Middle Eel results in a rate of about 1.0 cubic yard per acre per year.

2002- North Fork Eel TMDL Sediment Analysis: Six Rivers National Forest and Pacific Watershed Associates. This study involved two air photo studies, at different levels of detail, along with field sampling small sediment sources and extrapolation of field data to the remainder of the watershed, similar to the method used on the Middle Fork Eel. Results for landslide production from National Forest lands within the basin were 0.16 cubic yards per acre per year.

2002- Shelf Record of Climatic Changes in Flood Magnitude and Frequency, North-Coastal California: Geology Volume 30, Number 5 pages 395-398

APPENDIX 3: LIST OF AIR PHOTOS

APPENDIX 4: BEDROCK DESCRIPTIONS

APPENDIX 5: CONVERTING CUYDS TO TONS

CONVERSION OF TONS TO CUBIC YARDS

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	In Situ Wt.	Tons/cuyd	Loose Wt.	Tons/cuyd
Earth	3200	1.6	2550	1.275
Clay	3400	1.7	2800	1.4
Loam	2600	1.3	2100	1.05
Sand	2700	1.35	2400	1.2
Rock/Soil*	3850	1.925	2900	1.45
Sandstone	4250	2.125	2550	1.275
Shale	2800	1.4	2100	1.05
Granite**	4600	2.3	2800	1.4
Basalt	5000	2.5	3300	1.65

*Average for all rock types; 50/50 mixture of rock and soil.
**Weight is for broken, not massive rock
Data Taken From: Caterpillar Inc. 1991. Caterpillar Performance Handbook, 22nd Edition. A Cat (registered trade mark) publication by Caterpillar Inc., Peoria, Illinois, U.S.A. p. 24-4. 1 table, October 1991.